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memorandum

TO : Chris Simpson

FROM : Parviz Namjou

DATE: 23 Dec 2014

RE: Three Kings Development: Groundwater Level Response to Storm Events

This memo has been prepared at the request of Fletcher Residential Ltd a branch of Fletcher Concrete and Infrastructure Ltd (Fletcher) to provide further information on the 3D numerical groundwater model constructed and used in the 'Three Kings Renewal Stormwater Management Plan – Option 15H2 (PDP 2014).

1.0 Introduction

The proposed Three Kings Development involves turning the quarry into a residential development including apartments, townhouses and open space areas and parks. The development is expected to house between 3,500 and 4,275 people.

PDP was engaged in 2013 to assess the potential effects of stormwater discharges and develop a storm water management concept for the proposed development of the Three Kings Quarry. Details of the proposed storm water management plan are given in PDP (2014).

Stormwater runoff within the Three Kings Renewal project will be managed through a combination of soakage, reticulated networks, stormwater treatment and overland flow. Treatment will include sedimentation ponds, a wetland channel with three cells on the eastern side of the site, swales and rain-gardens. Surface water which does not infiltrate and is not directly discharged to soakage will be conveyed to soakage areas adjacent to the wetland and two main storage areas toward the south of the site. These storage facilities comprise above ground storage (depression storage) and underground storage (rock fills).

As part of this project, a groundwater model was developed to quantify the rise in groundwater levels in the Three Kings volcanic cone (scoria and basalt) as a result of large rainfall events. The 3D model is based on the original groundwater model developed as part of the quarry dewatering consent conditions (PDP 2003 and 2005).

1.1 Background

The Three Kings Quarry is located to the west of Mt Eden Road, Three Kings, Auckland, and within the Three Kings Volcanic cones. Winstone Aggregates (Winstone), a division of Fletcher has been dewatering the quarry since March 1999. However, the extraction of scoria from the quarry was ongoing for about 80 years. A resource consent for the dewatering activities was granted by the Auckland Regional Council (ARC) in March 1997 (reference 949798) which will expire in 31 December 2030. The quarry excavation and deepening ceased in 2009 when a new consent was lodged for the quarry rehabilitation. The consent was for the progressive placing of fill in the quarried-out areas and discharges of contaminants to land and/or water. However, the quarry dewatering is still occurring.

The ongoing groundwater pumping has caused the groundwater level to drop about 23 m from the pre-quarry groundwater level of about RL56.5 m to RL34m within the Three Kings volcanic cones.

A monitoring and contingency plan "The Three Kings Quarry Dewatering, Monitoring and Contingency Plan for Ground Subsidence" dated 25 November 1998, was prepared as required under the resource consent conditions. The conditions were revised in May 1999 and February 2004. As part of these updated monitoring conditions, a groundwater level monitoring programme was implemented. The conditions also required that the groundwater model (which was developed as part of the consent application, PDP 2003) should be reviewed annually to track calibration accuracy, to validate drawdown predictions and to ensure recharge estimates are reasonable. The main objective of the above model was to make predictions of future responses of the groundwater system in the Waitemata Group (ECBF) from the quarry dewatering so that potential settlement effects can be assessed.

1.2 Previous Work

Ground investigation, geological interpretation, development of geological and hydrogeological conceptual models and groundwater modelling have been carried out previously for the quarry. A number of reports were prepared in the early to mid-1990's relating to borehole/piezometer installations, geological setting, initial groundwater assessment and drawdown predictions, and anticipated land settlement predictions. These reports were required to obtain the resource consent granted in March 1997 for the quarry dewatering.

Notable studies include those carried out by Grant Fisher (2003), Carryer Associates (1994), Groundsearch EES (1996), Tonkin and Taylor Ltd (1998 and 2003), Subsurface Imaging (2002) and PDP (2003 to 2014).

The primary source of geological information is the large number of boreholes (37 bores) which have been drilled across and around the site. These are located both inside and outside the crater and extend down to nearly -10mRL. The locations of these bores are shown in Appendix A.1.

Subsurface Imaging (2002) used some of the groundwater level data to conclude that linear extrapolation of the drawdown rate would result in a water table elevation of 0 m RL after approximately 6 years of steady pumping at a rate of 5,000 m^3/day. They also concluded that a zone of higher permeability Waitemata Group surrounded the volcanic crater, in which groundwater drawdown matched drawdown levels recorded within the crater. It was suggested that this zone was due to effects of the volcanic explosion, however the aerial extent of this zone was not determined due to insufficient field data (i.e. the zone was not delineated).

PDP developed a numerical model in 2003 and 2005 for the volcanic cone and surrounding Waitemata Group as part of the resource consent conditions for groundwater take (dewatering). The model comprises a high permeability, approximately circular crater surrounded by low permeability non-extrusive sediments (Waitemata Group). The main focus of the model at that stage was to predict groundwater drawdown in the Waitemata Group rather than analysing groundwater behaviour within the crater itself. PDP have used groundwater level monitoring data and the above mentioned 3D numerical model to assess the drawdown effects in the Waitemata Group as part of the annual monitoring plan for the dewatering consent (e.g. PDP 2003b and 2005a/b).

More recently, a preliminary assessment was carried out by PDP (2008) to investigate the contamination effects of the quarry managed fill on groundwater and to predict the level of volumetric dilution that may occur at the groundwater abstraction discharge point.

1.3 Objectives

As part of the design of the underground water storage detention facilities, it is necessary to define the freeboard within the unsaturated zone between the base of the facility and the normal water table level that is required to host the groundwater level rise associated with the design storm. To assist this process the current modelling study was undertaken to estimate the rise in the natural groundwater level as a result of a 100-year ARI (Average Recurrence

Interval) 24 hour duration rainfall event. The study has assumed that the current pumping from the quarry will cease prior to the development and the water table will rise to its natural level (above RL 56.5m).

1.4 Scope

The modelling undertaken has focussed estimating the general rise in the water table that will occur under the proposed development area during the design storm. It makes allowance for stormwater soakage inputs to the local groundwater catchment from other soakage facilities associated with roads, residential and commercial areas. Modelling of these flows has been undertaken separately and is discussed in PDP 2014. Modelling of the hydraulic behaviour of the proposed soakage facilities for the development, specifically the proposed soakage trenches near the playing fields, and the effect of these individually on the unsaturated zone (groundwater mounding), has also been undertaken separately and is discussed in PDP 2014a.

2.0 Conceptual Groundwater Model

The conceptual model for the groundwater within and outside the cone is discussed previously by PDP (2003a, 2005b and 2008). A generalised conceptual hydrogeological model for the site is shown in Figure 1 and the main elements of the conceptual model discussed below.

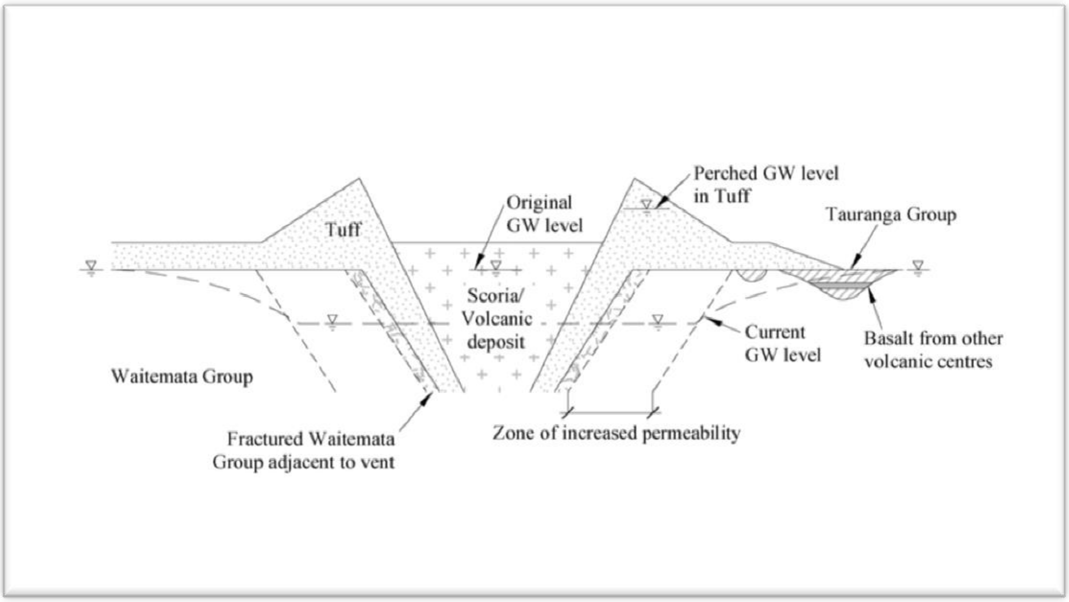


Figure 1: A Generalised Conceptual Groundwater Model (showing the volcanic cone and zone of increased permeability within the Waitemata Group)

2.1 Geology

The geology in and around the Three Kings quarry can be divided into four main soil and rock types: basalt, scoria, tuff, and non-extrusive sediments (Waitemata Group). The Three Kings volcanic crater, geology and location of the existing bores are shown in Appendix A.1.

Basalt, scoria and some tuff dominate the quarry area and form a roughly circular outcrop defined by the volcanic crater (as shown in Appendix A.1). The basalt can be found intercalated with, or intruded into, the scoria and tuff forming a high elevation lava moat around the periphery of the crater (above RL60m). The bulk of the tuff and non-extrusive sediments (principally Waitemata Group and younger Tauranga Group) occur outside this area. The tuff deposits vary in thickness (~4 m and 18 m, PDP 2003a), generally with less tuff deposits present southwest and west of the quarried crater. The zone of weathered Waitemata Group varies in thickness between approximately 4m and 10m, with thickness generally increasing with increased distance from the crater. The Waitemata Group in the vicinity of the Three Kings crater appear to be sub-horizontal in nature, with some steeper dipping zones present locally (Fisher 2003). Two nearby ARC bores (4693 and 4694) indicate that the Waitemata Group extend to approximately 500 m in depth (PDP 2003a).

Previous work has identified the presence of four volcanic cones within the Three Kings volcanic complex – Big King, East King, Highest King, and Central Cone. Basaltic feeder pipes might reasonably be expected at the centre of each of these cones with scoria surrounding them. A basaltic feeder pipe is currently visible toward the south east corner of the quarry at the former location of the Highest King.

From the borehole information alone it is difficult to see any well-defined structures within the crater. However, great thicknesses of basalt are seen in boreholes 5B and 14 located close to the dyke-like intrusion and diametrically opposite in boreholes 4B and 17. Between the two and roughly centrally, BH8A, shows a relatively large thickness of basalt below scoria.

Estimates of the depth to the base of the cone have been made in previous work. Based on the angle of repose of the granular sediments forming the crater walls - the slope on the cone was suggested to be 37 degrees (Fisher 2003). This would place the vertex of the inverted cone-shaped crater at somewhere between RL-160m and RL-170m.

The Three Kings crater sits within the Waitemata Group sediments. Tuff blown out during the initial stages of eruption sits on top of these deposits and forms a bund-like feature, referred to as a tuff ring, around the crater. Previous work suggests that basalt lava filled a 'moat' between the cones and the Tuff/Waitemata bund, and this can be seen in boreholes located toward the southern, eastern, and northern edge of the crater (boreholes 6, 6A, 18, 18A, 19, 11A, 11B).

Based on the existing information (e.g. PDP 2008), a breach of the northern boundary of the crater has occurred where a lava flow exited the crater and continued down to Meola and Western Springs (there is no evidence of any lava flow breach toward the Onehunga Aquifer).

2.2 Hydrogeology

Groundwater Movement

The groundwater movement in the quarry and its vicinity are contained primarily within two hydrogeological units. These are: i) the scoria and basalt within the cone, and ii) the surrounding Waitemata Group.

Before the dewatering, groundwater in the cone was acting similar to a 'bucket' (as shown in Figure 1) with sufficient recharge causing overflowing from a breach in the tuff ring (i.e. 'edge of bucket') located north of the quarry. Following the dewatering the groundwater has been drawn down by about 23m and now predominately flows towards the quarry dewatering pumping well (which is referred to as DW in Appendix A.1). Any cessation of the groundwater abstraction within the Three Kings volcanic cones, causes the groundwater level to recover to their pre-dewatering levels of around RL 56.5m. This will result in resumption of groundwater throughflow from the cone along the Three Kings lava flows and towards the Western Springs.

Groundwater Levels

The pre-dewatering groundwater levels in the bores inside the cones as shown in Table 1 were generally similar, with an average elevation of about RL56.5m. The groundwater dewatering at the cone started in 1999 and currently is held through pumping at about RL34m. The pumping record (daily record) and hydrographs for the above monitoring boreholes are shown in Appendix A.2 and A.3 respectively.

Table 1: Average Pre-dewatering Groundwater Levels in Scoria/Basalt within the Three Kings Crater

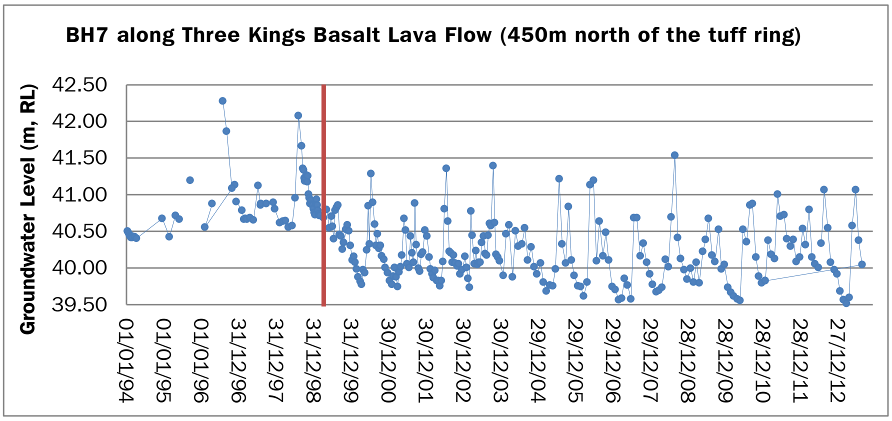
Bore ID	Groundwater Level (m, RL)
BH1B	56.77
BH2B	56.55
BH5B	56.12
BH17	56.59
BH3	56.51
BH14	56.60
Average	**56.52**

The groundwater level hydrographs shows that most bores have reached their maximum response to the dewatering and are currently close to steady-state. Groundwater levels in the cone (basalt and scoria) have behaved similarly suggesting that there are no significant hydraulic barriers within the crater. This is evident from the groundwater hydrographs shown in Appendix A.3. The groundwater level in the Waitemata Group adjoining the cone ranges from RL 60m to RL 35m with perched groundwater in various zones at higher elevations (PDP 2003a).

Tuff Ring Breach

A recent study (PDP 2013) on the nature of the tuff ring breach using the groundwater level monitoring data inside and outside the cone indicates that the tuff ring breach is about 8.5m below the pre-dewatering groundwater level at RL48m (RL56.5m - 8.5m). As the groundwater level was dropped below the base of the tuff ring breach the connection between the groundwater inside and outside the cone was ceased. This is evident from the historical groundwater records for the bores in basalt/scoria drilled inside and outside the cones. The groundwater level hydrographs for BH2B (inside the cone) and BH7 (outside the cone - 330m from the lip of the cone) are shown in Figure 2 (the location of the bores is shown in Appendix A.1).

As a result of the dewatering, the groundwater level in BH2B (inside the cone) was gradually dropped over 3.6 years from RL56.5m to RL34m (Figure 2). In contrast the groundwater level in BH7 was dropped by about one meter (from RL41m to RL40m) after the pumping and stabilised, showing only seasonal variations (Figure 2). The different responses to dewatering indicates that the groundwater level in BH7 in the basalt aquifer (sourced from the Three Kings lava flows) became disconnected from the groundwater from the rest of the aquifer inside the cones after the groundwater level was dropped below the tuff ring breach. The width of the tuff ring breach based on the geological map (Appendix A.1) is estimated to be about 490m.



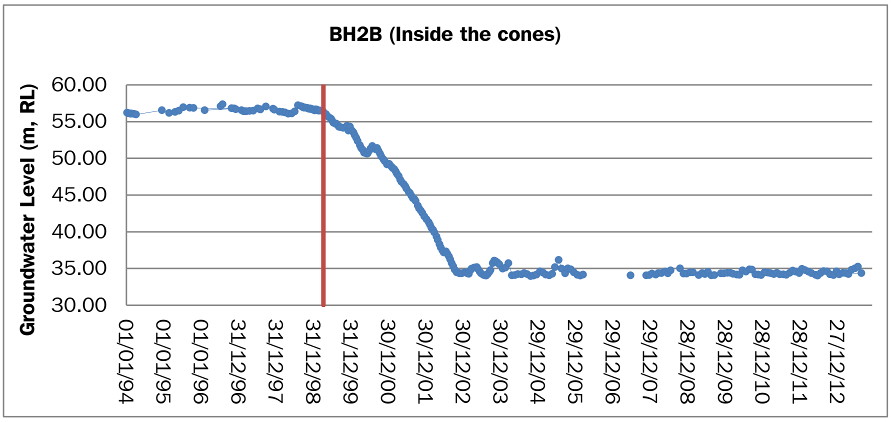


Figure 2: Groundwater Level Hydrographs for BH7 (outside the cones) and BH2B (inside the cones)

Hydrogeological Properties

Previous work (PDP 2003a, 2005b and 2008) has shown high permeability volcanics within the volcanic cone (K = 2 x 10^{-4}m/s) and lower permeability for the disturbed Waitemata Group sediments (K = 9.4 x 10^{-7}m/s). Based on the previous PDP study (PDP 2003), groundwater in the disturbed Waitemata Group is contained within a 200m wide collar of higher permeability sediments around the crater (Appendix A.1).

Based on the relatively uniform response of groundwater levels to pumping within the crater it is considered that there is no need to assign varying hydrogeological properties to the different lithologies seen in the crater. The existing data in the hydrogeological properties of the aquifer (PDP 2003a and 2005b) within the cone (scoria and basalt) and surrounding disturbed Waitemata Group is summarised in Table 2.

Table 2: Summary of Hydrogeological Properties (PDP 2003a and 2005b)

Lithological Unit	K_H (m/s)	K_v/K_H	Storage Coefficient	Model
Crater volcanics	2.0 x 10^{-4}	1	0.01*-0.1	PDP 2003 and PDP 2005 calibrated model
Disturbed Waitemata Group	9.4 x 10^{-7}	1	0.1 (S_y) 1 x 10^{-5} (S_s)	PDP 2003 calibrated model

* Based on the Global Aquifer Study (PDP 2005c)

Recharge

Before dewatering began, rainfall recharge to the crater would have been balanced predominantly by groundwater outflow in the form of overspill to the basalt flow to the north (discharging to Western Springs). Since the onset of steady-state dewatering the rainfall recharge has been balanced by outflow through the dewatering abstraction. The total long-term groundwater inflow to the pit under the current dewatering conditions is about 2,500 m^3/day. This includes some groundwater contribution from the surrounding Waitemata Group (disturbed zone) which is diverted to the pit.

The groundwater catchment for the above abstraction is limited to the cone (basalt and scoria) with an area of 81ha and the disturbed Waitemata Group with an area of about 83ha. The contribution from the undisturbed Waitemata Group is negligible due to its low permeability (1.5 x 10^{-8}m/s, PDP 2003a).

The recharge over the disturbed, fractured ECBF area (83 ha) outside the cones which contributes to the above flow is estimated previously by PDP to be about 10% of the annual rainfall or about 120 mm/year (PDP 2008). Therefore the contribution from the disturbed fractured ECBF is about 274 m^3/d and from the basalt and scoria within the cone is about 2230 m^3/d (2500 m^3/d - 274 m^3/d). Using the above pump out rate and cone area (about 81 ha), the recharge over the scoria and basalt is estimated to be about 83% of rainfall.

The tuff layers with their low permeability within the cone may form local perched layers (discontinuous zone of saturation) above the deeper and regional groundwater level in the cone. However, based on the geological logs for bores drilled inside the cones, the volcanic materials predominantly consist of scoria and basalt. From six bores drilled inside the cone (Table 1), the only tuff layer detected occurs in BH14 (Appendix A.1) from 1 to 4m below the ground level. Therefore, it is likely that the extent of these tuff layers within the cone is limited to local areas.

3.0 Groundwater Numerical Model

A simplified 3D numerical groundwater model was constructed for Three Kings residential development project based on the existing models (PDP 2003a and 2005b) developed as part of the dewatering consent conditions and contingency plan. The main difference between the existing models and the new model is the exclusion of the undisturbed Waitemata Group in the new model and refining of the model transient calibration using additional ground water level data, pumping rates and rainfall data.

The modelling code used was the 3D finite difference program MODFLOW (McDonald and Harbaugh, 1998). This is the most widely used program for 3D groundwater flow simulations.

Model Assumptions

The following assumptions were applied in the model:

1) The model only simulates the groundwater level within saturated zone (continuous zone of saturation).
2) The model assumes, the low permeability tuff layers (if occur) are sufficiently localised that don't form perched groundwater layers above the deeper and continuous groundwater within the scoria and basalt. Therefore such perched layers are not simulated in the model. As discussed before in Section 2, the drilling programme for bores outside the pit but within the cone don't support formation of the perched layer or multi aquifer conditions. Therefore the above assumption is reasonable.

Model Development

Model development was completed in the following stages:

- Set up model grid structure
- Assign Model Input Parameters
- Assign boundary conditions
- Calibrate the model
- Carry out predictive simulations for various scenarios.

3.1 Model Domain and Grid Structure

The model domain contains the volcanic cone and about 200 m zone of the disturbed Waitemata Group with a uniform grid spacing of about 10 m, vertically discretized into 9 model layers. The model domain and grid structure is shown in Figures 3 and Figure 4 respectively. The model covers a circular area with a radius of about 750m with a uniform grid resolution of about 10m.

The basalt and scoria within the cone are simulated with a thickness of about 400m as for the original model (PDP 2005b).

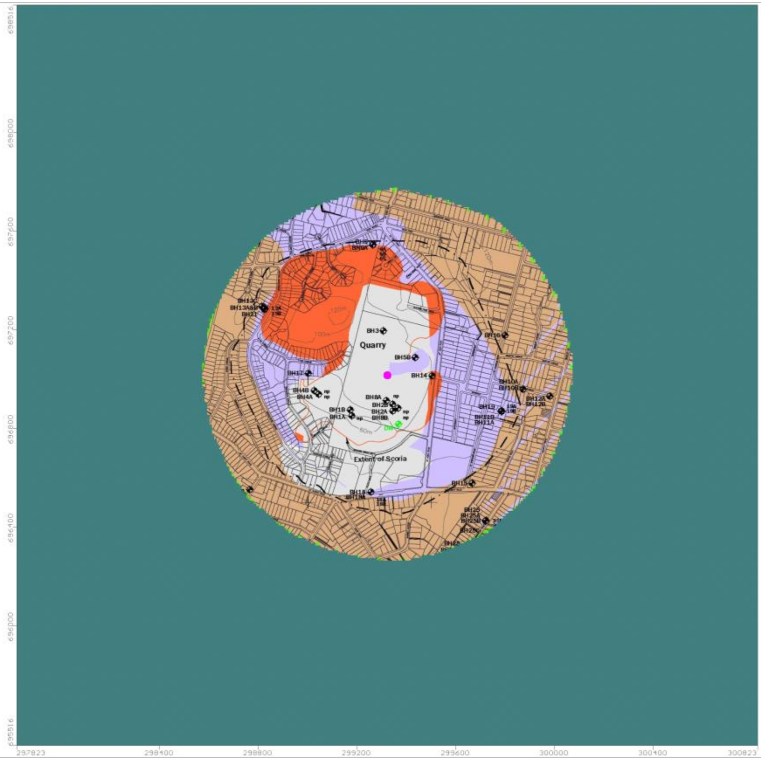


Figure 3: Model Domain

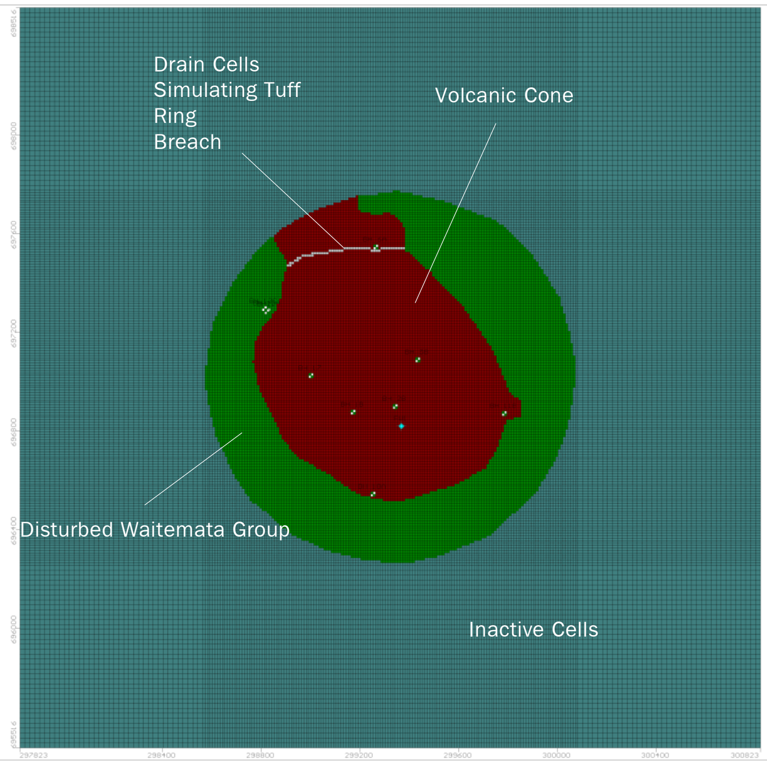


Figure 4: Model Grid and Boundary Conditions

3.2 Model Input Parameters

The initial aquifer hydraulic properties used in the model (for the basalt, scoria, and disturbed Waitemata Group units), are the same as that of the previously calibrated model presented (PDP 2005b) and given in Table 2.

3.3 Boundary Conditions

Two types of boundary conditions were assigned in the model:

- No-flow boundaries where the flux is zero;
- Specified head boundaries (free draining cells, i.e. with high conductance) for which the head is known at the boundary of the groundwater flow system at a particular time.
- Pumping (well/abstraction cells).

No flow-boundaries were set at the edges to the model flow domain, well outside the area of effect from the quarry (about 750 m away from the centre of the volcanic cone).

The focus of the current model is on the response of groundwater levels in the cone (basalt and scoria) to rainfall event. Therefore the model no-flow boundary was assigned along the boundary of undisturbed Waitemata Group. Considering the low permeability of undisturbed Waitemata Group (i.e. 1×10^{-8}m/s, PDP 2005b), its exclusion from the model is unlikely to have any effects on the predictions.

The drain boundary was assigned to nodes located along the tuff ring breach between RL 56.5m and RL 48m. The head along the drain cells were set at pre-dewatering groundwater level (RL 56.5m). Drain cells remove water from the aquifer at a rate proportional to the difference in heads between the aquifer and the water in the drain and are active only if the groundwater level in the cone is higher than the drain elevation.

The quarry pumping was simulated in the model using abstraction cells with specified pumping rates.

3.4 Model Calibration

As part of the quarry dewatering monitoring conditions, the groundwater levels, rainfall and dewatering pumping rates are being monitored. The original model was calibrated based on the above data from about 32 bores inside and outside the cone (PDP 2005b).

Further calibration has been undertaken for the current model to refine the storage parameters (if required) so the short-term groundwater response to rainfall can be assessed.

The focus of the current model calibration was on the recharge and storage parameters of the scoria and basalt in the cone (basalt and scoria) and no attempt was made to revise the previously calibrated hydraulic conductivity values. The current model calibration was checked using additional groundwater level data collected from two bores inside the cone (BH2B and BH5B) in 2014 with 3 min intervals and stabilised average groundwater pump out (i.e. additional pumping records since 2005). The updated pumping record was used to assess the long-term recharge under current steady state conditions. The time series groundwater level monitoring data was used to assess the aquifer storage parameters under transient conditions.

Steady State Calibration

The steady state calibration check was focussed on matching the historical no pumping groundwater level data. The average long term groundwater levels in the bores within the cone were used for this calibration (Table 3). The previously calibrated parameters were produced a reasonable match between the measured and calculated groundwater levels. However recharge in the cone was slightly reduced (from 89% to 83% of rainfall) to produce a better match with the current average long-term pumping rates (2500m^3/d). The calibrated model parameters are shown in Table 4.

Table 3: Steady State Pre-Quarry Calibration Results			
Name	Observed (m, RL)	Calculated (m, RL)	Difference (m)
BH14	56.60	57.06	0.46
BH17	56.59	57.02	0.43
BH1B	56.77	57.05	0.28
BH2B	56.55	57.06	0.51
BH3	56.51	56.99	0.48

Table 4: Steady State Calibrated Parameter		
Parameters	Basalt/Scoria	Disturbed Waitemata Group
Hydraulic Conductivity (m/s)	2×10^{-4} (1)	9.4×10^{-7} (1)
Recharge (mm/year)	1,000mm/y (83% of rainfall)	120mm/y (10% of rainfall)
1) *Based on PDP (2005)*		

The difference between measured and calculated groundwater level in bores within the cone was about 0.5 m with root mean squared error of 0.55 m. The predicted and observed groundwater for pre-dewatering conditions is shown in Table 3. The calibration residual is considered to be satisfactory and no attempt was made to revise further the previously calibrated hydraulic conductivity values as minor variability in hydraulic heads is expected due to variation in hydraulic properties of volcanic materials within the cone (basalt and scoria).

Note that setting a lower elevation of the tuff ring breach in the model would have produced a better calibration match. However, given the small and conservative difference between the measured and modelled water levels (ie the model will over predict the elevation of the groundwater rise) further adjustment to the model was not considered warranted.

The model water balance is shown in Table 5, with an acceptable mass percent discrepancy of 0.01%. The calibrated recharge rate correlate well with current steady state pumping rate of 2500m^3/d.

Table 5: Water Balance for Steady State Model (Pre-Dewatering Conditions)		
	Model input (m^3/d)	Model output (m^3/d)
Groundwater discharge (through drain cells)	0	2508.77
Recharge	2508.91	

Transient Calibration

For this study additional transient calibration was undertaken to check the previously estimated storage parameter of 0.1 (or 1%) within the cone. Two sets of data were used for the calibration:

- Historical pumping record and groundwater response to long-term pumping
- Short-term groundwater level response to rainfall events

1) Historical pumping record and groundwater response to long-term pumping

The observed groundwater level response to the pumping in the cone (BH2B) and pumping records (since 1999) were used for this calibration. The average pumping rate during this period was reduced from about 5000 to 2500 m^3/d. The storage coefficients were adjusted until the modelled groundwater fluctuations generally matched the measured levels. The calibration result is given in Figure 5 and the calibrated storage parameters are shown in Table 6.

Table 6: Calibrated Storage Parameters		
Lithological Unit	**Storage Coefficient**	**Model**
Crater volcanics	0.08 (S_y) 1 x 10^{-5} (S_s)	Current calibrated model
Disturbed Waitemata Group	0.1 (S_y) 1 x 10^{-5} (S_s)	PDP 2003 and PDP 2005 calibrated model

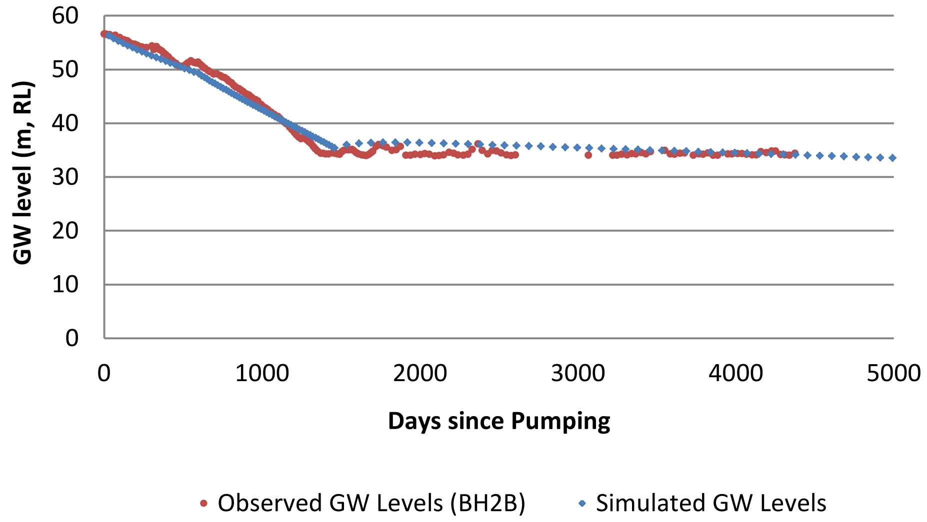


Figure 5: Calibration of Transient Groundwater Model (pumping

2) Short-term groundwater level response to rainfall events

Additional storage calibration modelling has also been undertaken (post-issuing of the 15H2 stormwater report, PDP, 2014) using short-term groundwater level response to rainfall events. The aim of this exercise was to check the appropriateness of the storage parameters by checking the model short-term groundwater level response to rainfall events.

This has involved the installation of pressure transducers within quarry pit bores BH2B and BH5B, between April and November 2014. The pressure transducers were set to record groundwater levels at a frequency of 3 minutes. The exercise has provided high resolution hydrograph data which is ideal for assessing recharge responses from rainfall events, which are able to be accurately measured by the site rain gauge (daily rainfall totals). The pumping within this period was varied between 2,000 to 3,200m^3/d in order to prevent any groundwater flooding of the quarry floor. The groundwater level hydrographs (BH5B and BH2B) and monitored quarry dewatering pumping rates are shown in Figure 6.

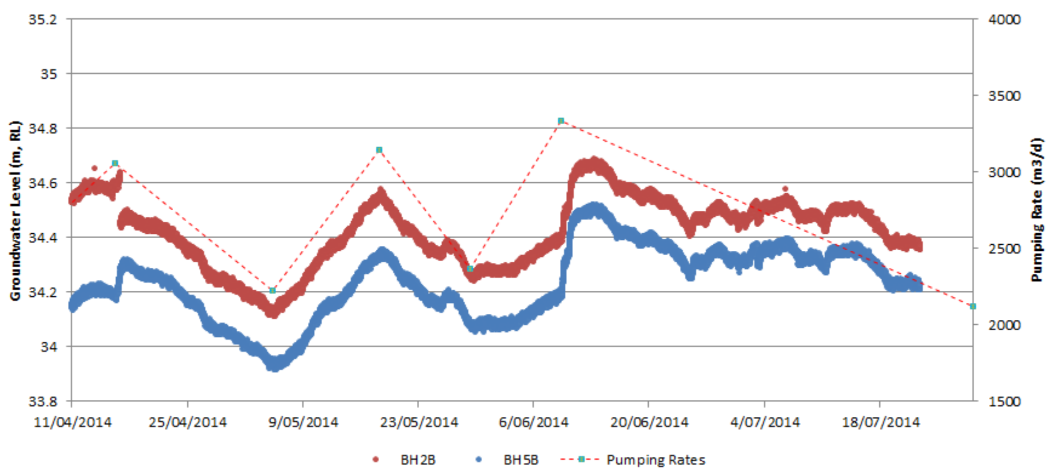


Figure 6: Groundwater Level Hydrographs and Monitored Pumping Rate

On June 10 2014, a daily total 54.4 mm of rain was recorded, which was preceded by a relatively dry period. The daily rainfalls and corresponding groundwater level responses before and after the event are summarised in Table 7.

Table 7: BH2B Groundwater head level and site daily rainfall

Time Period	Site Rainfall Total (mm)	BH5B Groundwater Level Start (m RL)	BH2B Groundwater Level End (m RL)
31 May 2014 to 8 June 2014	0	34.63	34.73
9-Jun-14	12	34.73	34.73
10-Jun-14	54.4	34.73	34.9
11-Jun-14	30.6	34.9	35.02
12-Jun-14	1.4	35.02	35.05

Considering there was similar response of both monitoring (BH2B and BH5B) bores to the rainfall events, the data for BH5B was used for this calibration assessment. The hydrograph of BH5B and daily site rainfall totals are presented graphically in Figure 7.

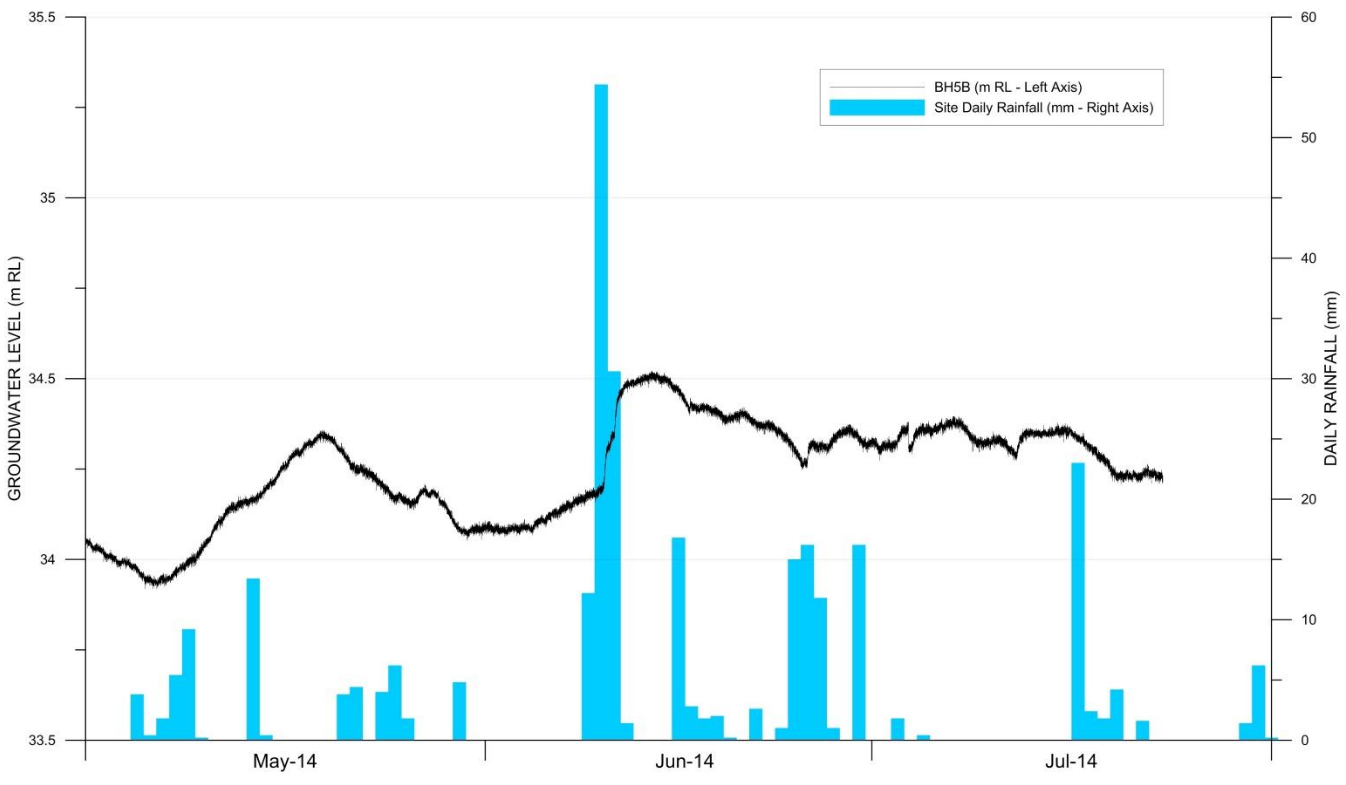


Figure 7: BH5B hydrograph and site daily rainfall

Figure 7 shows a rapid increase in BH5B groundwater level on 10 June 2014 when the 54.4 mm rain event occurrs. The gradual groundwater level rise (~0.1 m) during the period 31 May to 8 June 2014 when no rainfall was recorded, is likely associated with the dewatering operations i.e. pumping rate lowering during this time causing a small rise in groundwater level. However there is no continious pumping record to confirm this. As discussed above, the aim of the variation in pumping rate is to avoid the quarry floor to be flooded and to maintain the groundwater levels at about RL34m.

A transient scenario within the groundwater model was created to simulate the 54.4 mm rainfall event and associated groundwater response. The groundwater level at the pumping well is fixed at RL34m, which is the current long-term average groundwater level in the cone and the recharge rate is assumed to be similar to 83% of rainfall for the scoria and basalt and 10% for the disturbed Waitemata Group (Table 4).

The best calibration, whilst still ensuring the model remains conservative i.e. over estimates the influence of recharge events, was achieved using the specific yield (storage) of 0.08 (or 8%). This is in agreement with upper range of the storage identified as part of the GAS study (0.01 to 0.08, PDP 2005c) and slightly less than the previously estimated storage value of 0.1 (PDP 2003a and 2005b).

The model predicted groundwater level rise for the storage of 0.08 (8%) was about 0.46m as shown in Figure 8. This is about 0.13m more than the observed groundwater response to the rainfall event (Figure 8). The available pumping records (Figure 6), indicates a rise in pumping rate just before the event (Figure 6), this may have affected the groundwater response to the rainfall event (the quarry pump is operated manually). Therefore conservatively, no attempt was made to increase the storage parameter to achieve a better match.

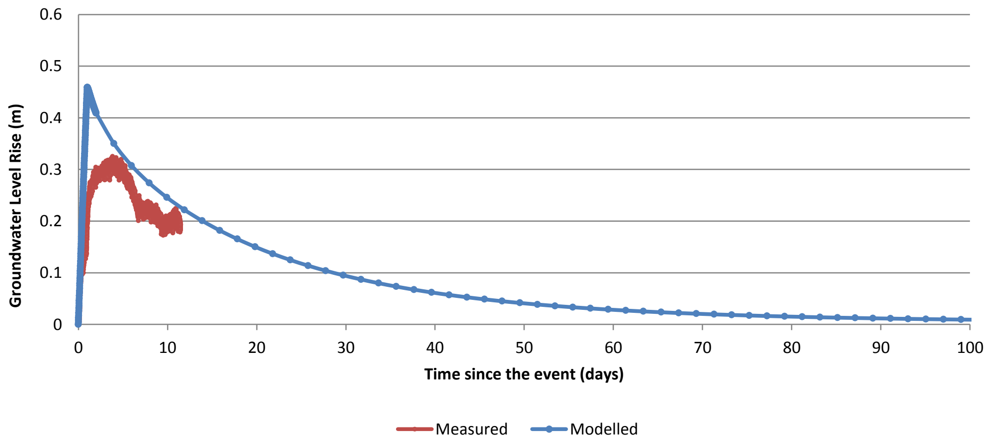


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Figure 8: BH5B head response to a 55 mm (over 24 hours) rainfall event

3.5 Sensitivity and Uncertainty Analysis

Sensitivity analysis has been carried out as part of the original models (PDP 2003a) and the results are considered to be relevant for the existing model. The results indicated that the model is most sensitive to both recharge and hydraulic conductivity values.

In the current study additional sensitivity runs were carried out to assess the model sensitivity to storage parameters. The storage parameter governs the transient response of the groundwater level to rainfall events. By increasing the storage of scoria and basalt to 20% or 0.2 (about twice the calibrated value of 8%) without changing any other parameters, the predicted drawdown in BH2B as a result of the quarry pumping is about 10m less than measured (Figure 9). While, by reducing the storage of scoria and basalt to 1% (0.01), the predicted drawdown for the same bore is about 10m more than what is being measured (Figure 10).

Note that the modelling assumes that the watertable response to storm events that occurs at its present pumped level of RL34m will be identical with when the groundwater level has recovered to RL 56.5m(its natural level). This is because the model calibrates well with a constant storativity value during the period when the quarry was dewatered to its current level between 1999 and 2002. The geological model also indicates this is a reasonable conclusion as the gross makeup of scoria and basalt within the crater over this range in levels is expected to be relatively constant.

The uncertainty results of this and previous studies indicate that calibrated parameters are reasonably conservative and suitable for assessing the effects of rainfall events on groundwater levels.

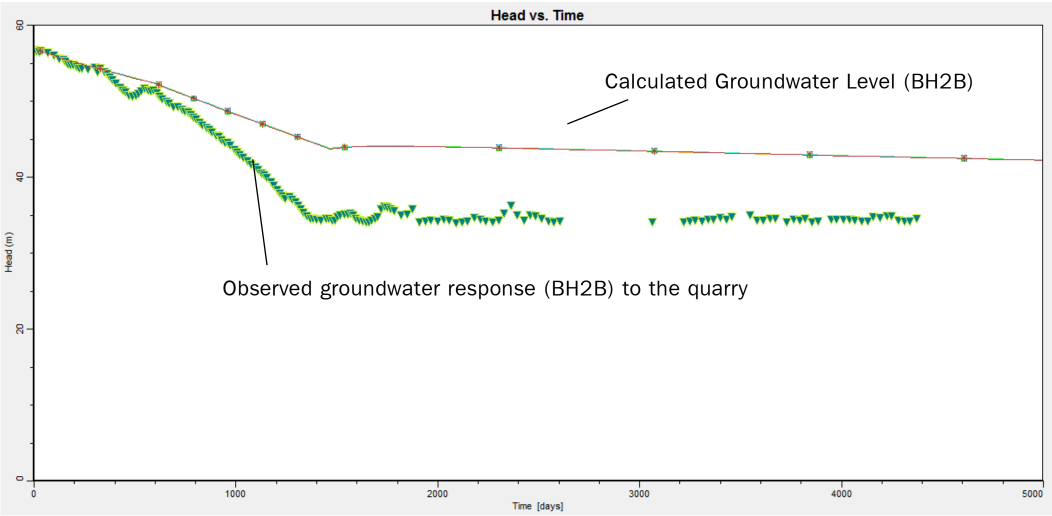


Figure 9: Sensitivity Results: Increasing scoria and basalt storage by two times (S=0.2 or 20%)

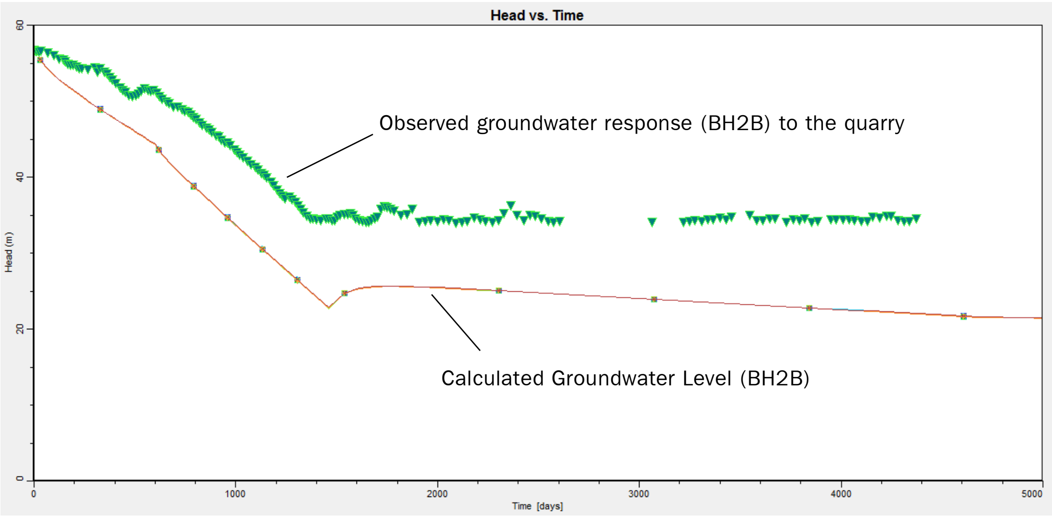


Figure 10: Sensitivity Results: Reducing Scoria and Basalt storage to 0.01 (1%)

4.0 Model Results

The above calibrated model was setup to simulate effects of rainfall induced infiltration from peak flows on the groundwater levels in the cone as a result of 100-year ARI 24 hour duration rainfall event. The model assumes that the groundwater levels are recovered to pre-dewatering conditions (RL56.5m) before the event.

Input parameters

For the simulations the backfill to the quarry was added to the model to match the conditions that will exist when the development is complete. The fill permeability was set between 2 x 10^{-5} and 1 x 10^{-7}m/s. However, as the runoff over the fill will be diverted to soakage in scoria/basalt, the fill permeability does not affect the predicted water level rise in the cone.

In order to model the groundwater response during storm events, A HEC-HMS surface water model was used to determine the rate of infiltration of stormwater to ground during the 1% AEP events (PDP 2014). The soakage catchment area was determined based on existing landuse, soakage distribution and geology. This overall catchment was divided into 7 catchments and 15 sub-catchments. The catchments are shown in Appendix A.4. To be conservative it was assumed that those (developed) sub-catchments already treated by soakage devices had the capacity to discharge the peak flow rate of the 2 year storm event to ground.

All stormwater which did not contribute to runoff was assumed to enter the groundwater system (no allowance for evapotranspiration has been made). Results from the HEC-HMS model gave a volume of stormwater discharged to ground. These results were converted to a depth of infiltrated stormwater over the area of each catchment. This infiltration was then divided over the 24 hour length of the design storm event to determine the rate of infiltration over the time period. The model infiltration for 24h 1% AEP event is shown in Table 8.

Table 8: Applied Infiltration Rate for 24h duration Storm Event

Catchments (Infiltration Zones)	a	b	c	d	e	f	g
Area (km^2)	0.82	0.18	0.45	0.07	0.03	0.03	0.03
10-year (mm)[1]	69.39	80.33	65.87	113.22	19.75	4.02	113.22
100-year (mm)[2]	97.84	112.71	88.10	167.60	21.99	5.05	167.60

1) Corresponds to 136mm rainfall depth
2) Corresponds to 240mm rainfall depth

Model Results

The modelling results indicate that a 100 year rainfall event causes about a 1.2m rise in the groundwater level in the centre of the cone (Figure 11). A 10 year event causes about 0.9m rise in groundwater level. Considering the observed seasonal variations in groundwater levels for bores in the cone (Figure 7) such rises are not unexpected.

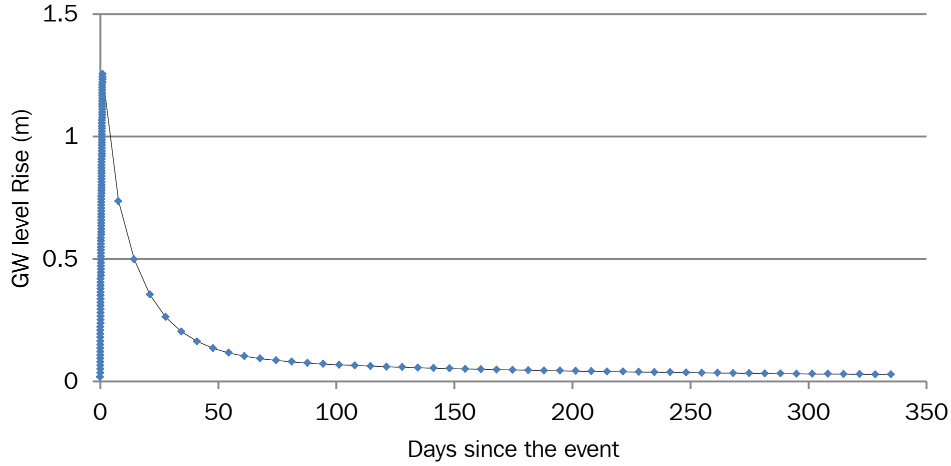


Figure 11: Groundwater Level Rise after 100-year ARI Rainfall Event

As discussed above, the modelling results are expected to be conservative and the groundwater level response to the design storm event is unlikely to exceed the above prediction.

The above results have been used in the Stormwater Management Report to set design levels for short-term rise in groundwater levels (Section 4, PDP 2014).

Please contact me if you require any other information on the above model.

Kind Regards
Parviz Namjou

References

Fisher G (Industrial Geology) (2003). Geological Update for Three Kings Quarry, Prepared for Winstone Aggregates.

Carryer & Associates Ltd (1994) Geological overview of Three Kings quarry and surrounding area, Carryer & Associates Ltd, 8 July 1994

GroundSearch EES Ltd (1996) Three Kings dewatering study supplementary report 3, GroundSearch EES Ltd, November 1996

Subsurface Imaging (2002) Report on Groundwater Model Review, Three Kings Quarry, prepared for Winstone Aggregates.

Tonkin and Taylor (2003) Three Kings Quarry Dewatering Review of Settlement Predictions, February 2003, Prepared by Tonkin and Taylor Limited for Winstone Aggregates.

Tonkin and Taylor (1998) Three Kings Quarry Dewatering, Monitoring and Contingency Plan for Ground Subsidence dated 25 November 1998, revised 14 May 1999.

Pattle Delamore Partners Ltd (2014) Three Kings Renewal Stormwater Management Plan– Option 15H2, Prepared for Fletcher Developments – a division of the Fletcher Construction Company Limited, July 2014.

Pattle Delamore Partners Ltd (2014a) Three Kings Renewal, Addendum to Stormwater Management Plan, prepared for The Fletcher Construction Company Ltd, 2 October 2014.

Pattle Delamore Partners Ltd (2013) Three Kings Development – Height of Groundwater Tuff Ring Breach, Prepared for The Fletcher Construction Company Ltd, 10 October 2013.

Pattle Delamore Partners Ltd (2008) Three Kings Quarry – Modelling of Cleanfill Drainage, Prepared for Winstone Aggregates, October 2008.

Pattle Delamore Partners Ltd (2005a) 2003/2004 Groundwater monitoring report, Three Kings quarry, PDP, 18 January 2005.

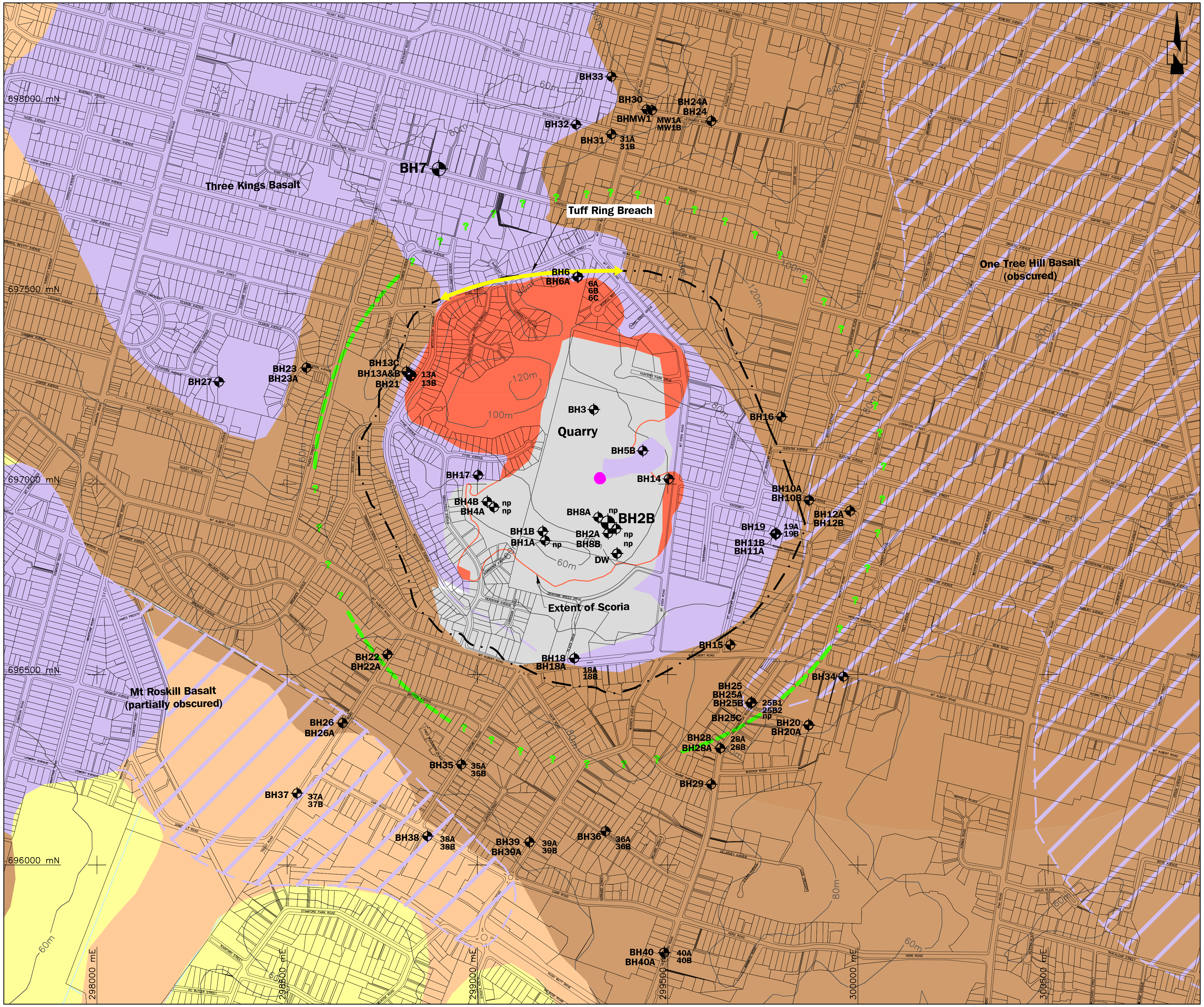
Pattle Delamore Partners Ltd (2005b) 2004/2005 Groundwater monitoring report, Three Kings quarry, PDP, 11 October 2005.

Pattle Delamore Partners Ltd (2005c) Regional Groundwater Model Development Report, Global Aquifer Study 2B1, Compiled for Metrowater and Auckland City.

Pattle Delamore Partners Ltd (2003a) Groundwater modelling of the Waitematas near Three Kings quarry (Vols 1 to 3), PDP, 3 February 2003.

Pattle Delamore Partners Ltd (2003b) Three Kings quarry dewatering: Assessment of groundwater information April 2003, PDP, 18 July 2003.

Appendix A.1
Geological Map



KEY:

- BH35 35A 35B — Investigation or Monitoring Borehole (e.g. BH35) and piezo names (e.g. 35A & 35B)
- BH np — Borehole with no piezo
- DW — Dewatering Well
- Centre of Crater
- ? — Estimated extent of High Permeability Zone (Waitematas)
- Modified Areas
- Recent Deposits
- Basalt
- Obscured Basalt
- Scoria
- Tuff Deposits
- ECBF Group
- Inferred Extent of Obscured Basalt
- Three Kings Crater

Note: Geology based partly on IGNS Geological Map, Sheet R11. Base map supplied by Grant Fisher Industrial Geology, dated Dec 01, and subsequently amended by PDP Ltd (Jan 08) to clarify areas of obscured basalt.

NO.	REVISION	DATE
A	ISSUED FOR REVIEW	OCT 13

Client : WINSTONE AGGREGATES

Project : Three Kings Quarry Development

Title : Borehole Location Plan

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Scale 1:10,000 (A3)

Project No. :	Figure No. :	REVISION :
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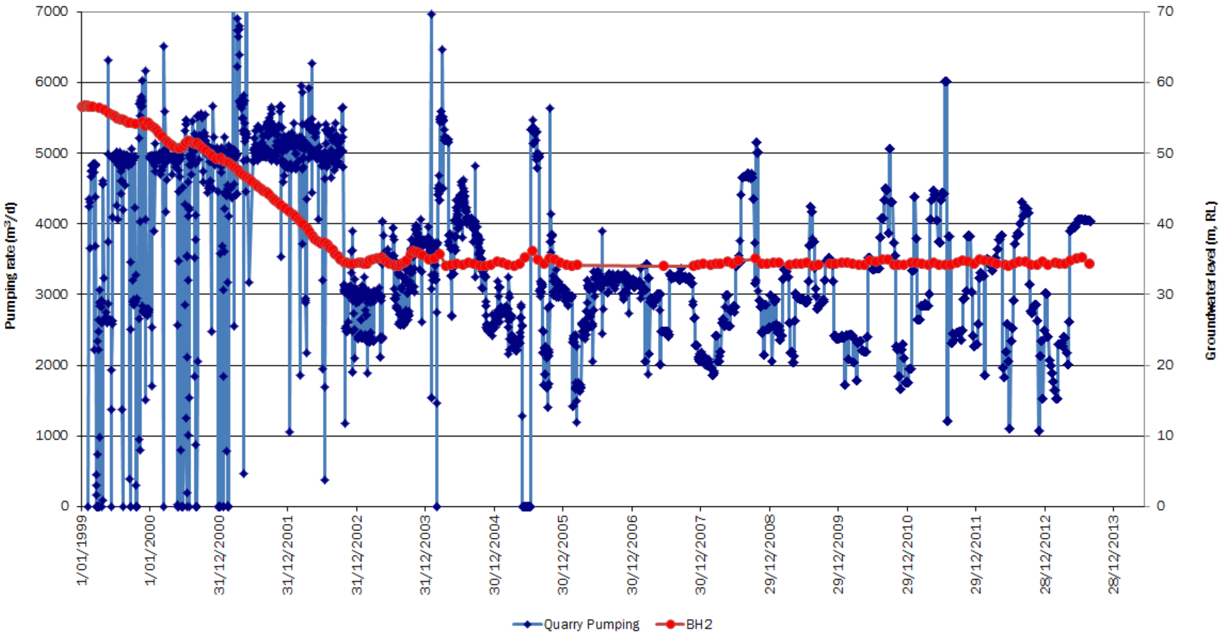
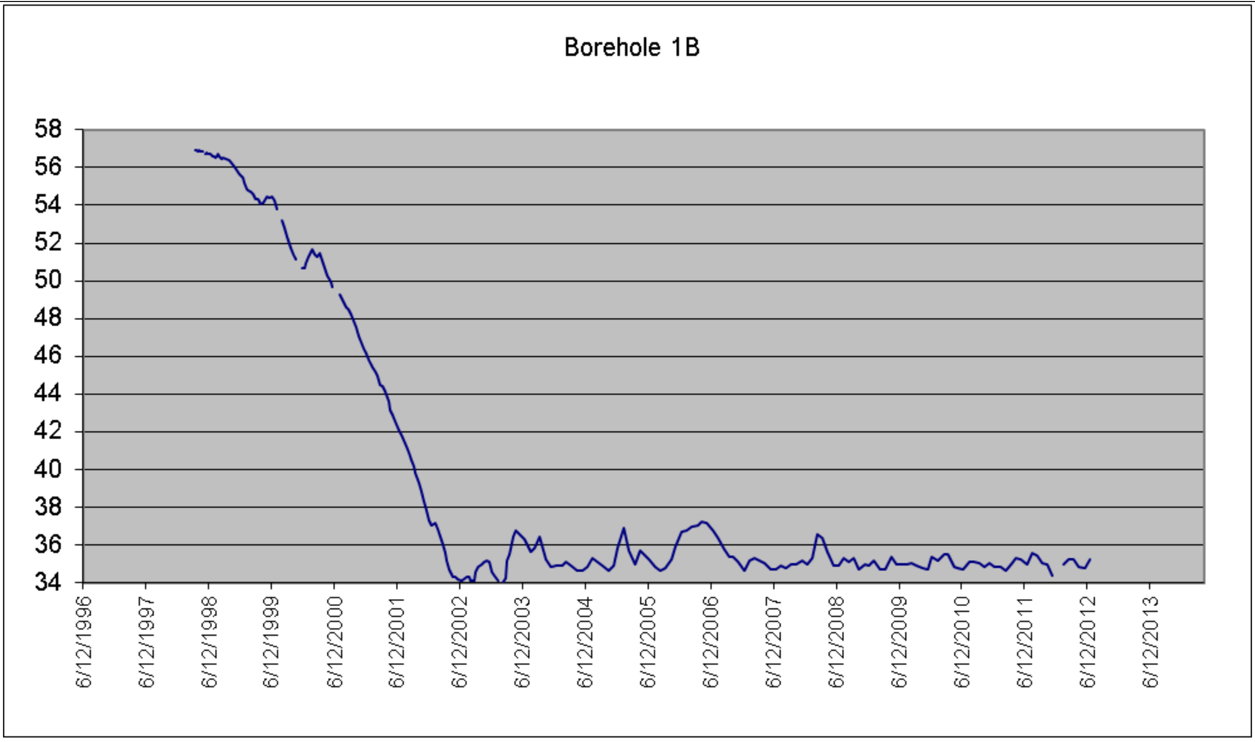
Appendix A.2

Quarry Pumping Rate



Appendix A.2: Quarry Pumping Rates and Groundwater Level Response in BH2B

Appendix A.3
Groundwater level Hydrographs for bores within the Cone (Scoria and Basalt)



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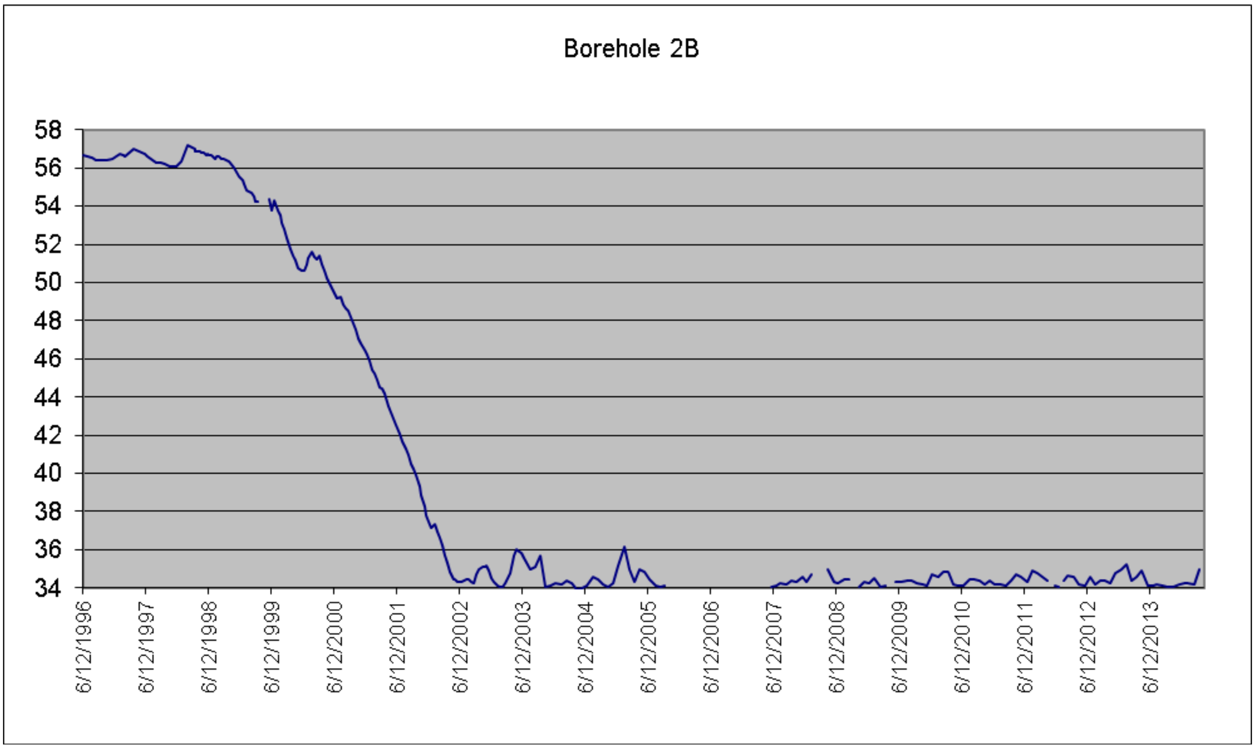

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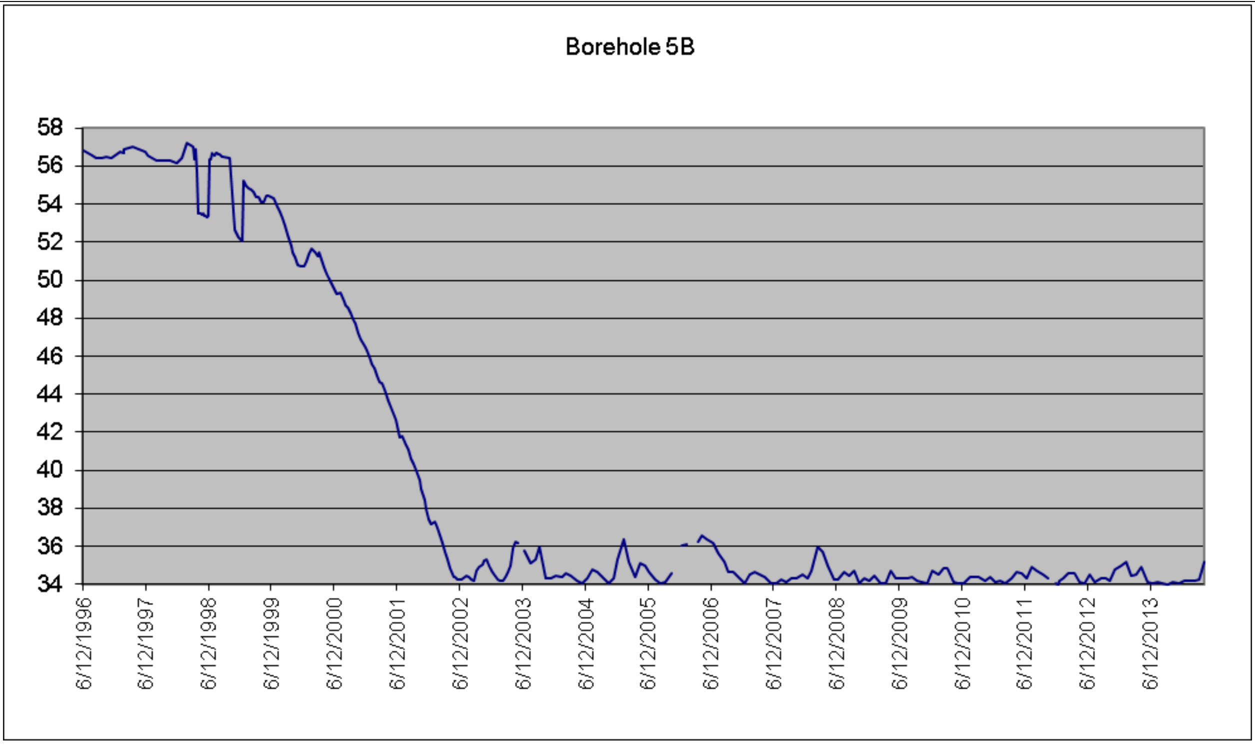
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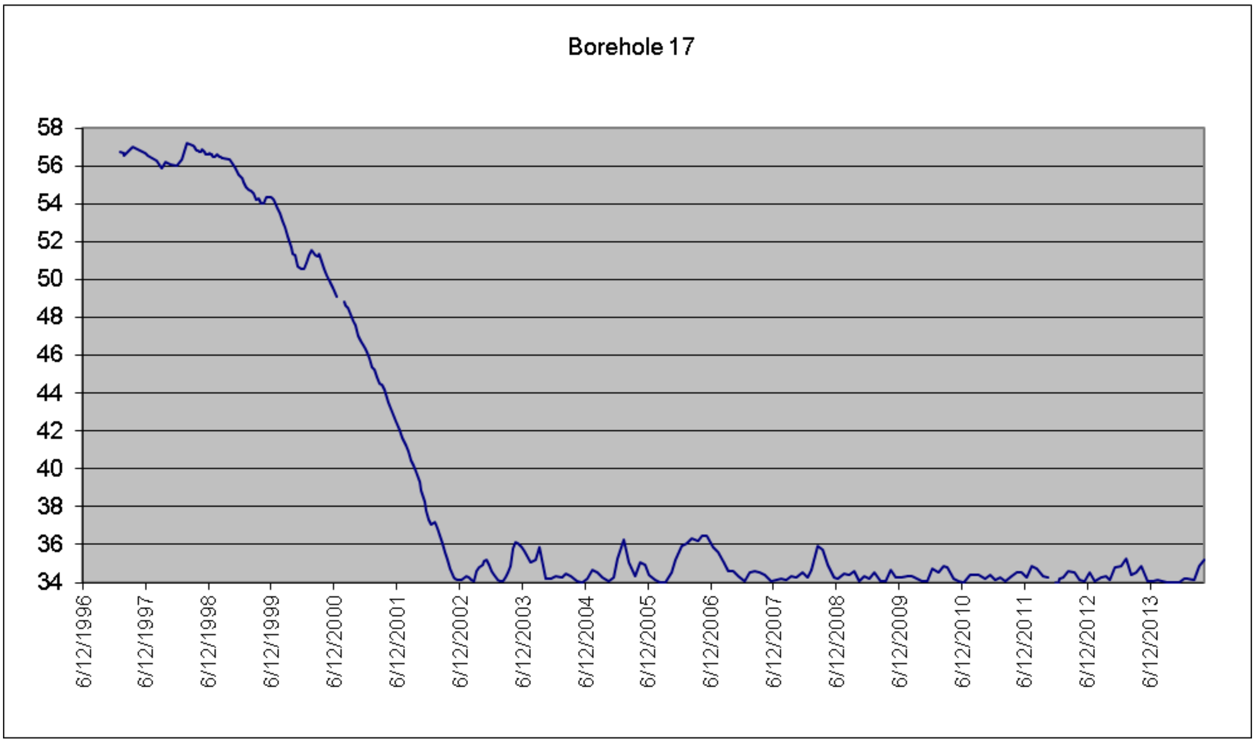
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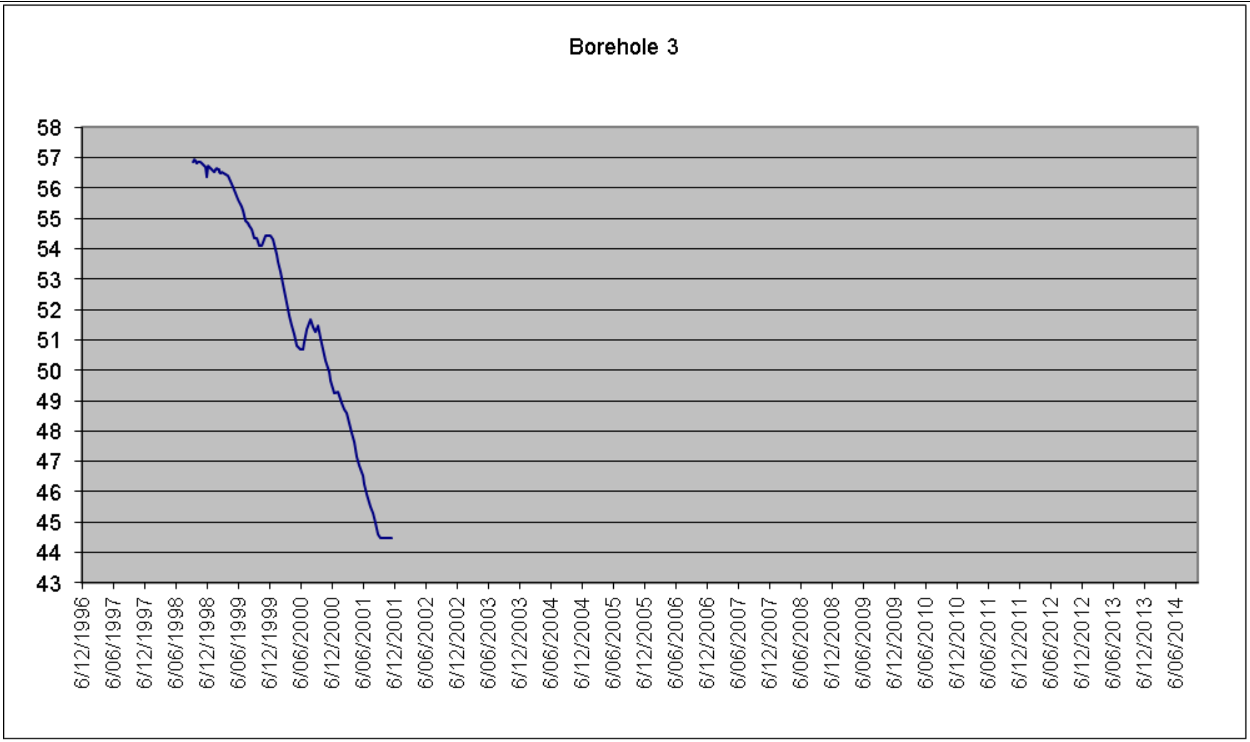
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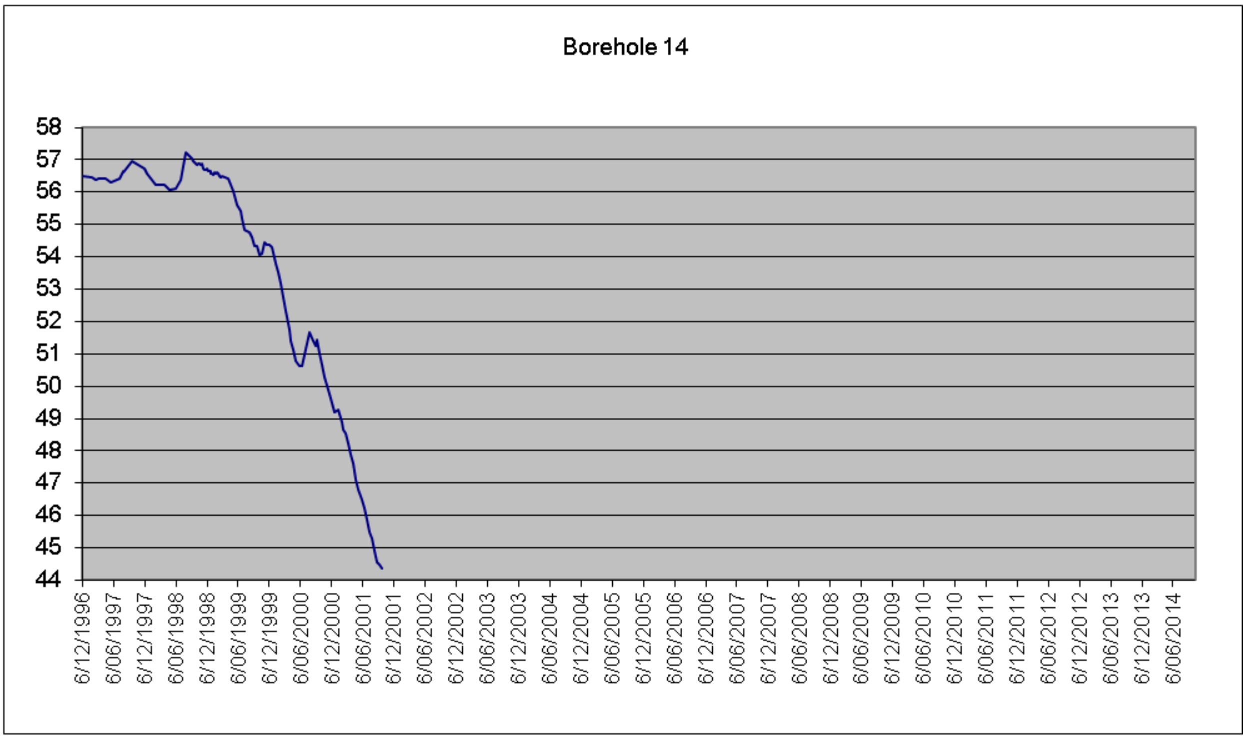
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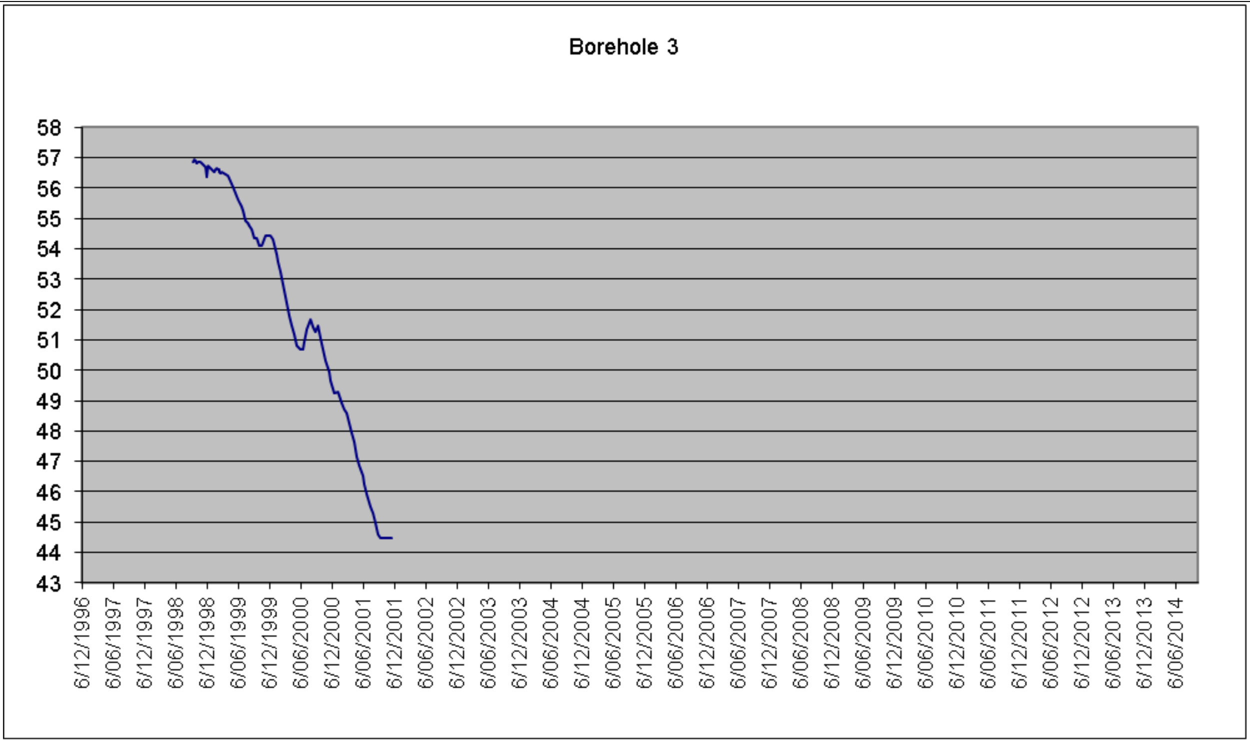
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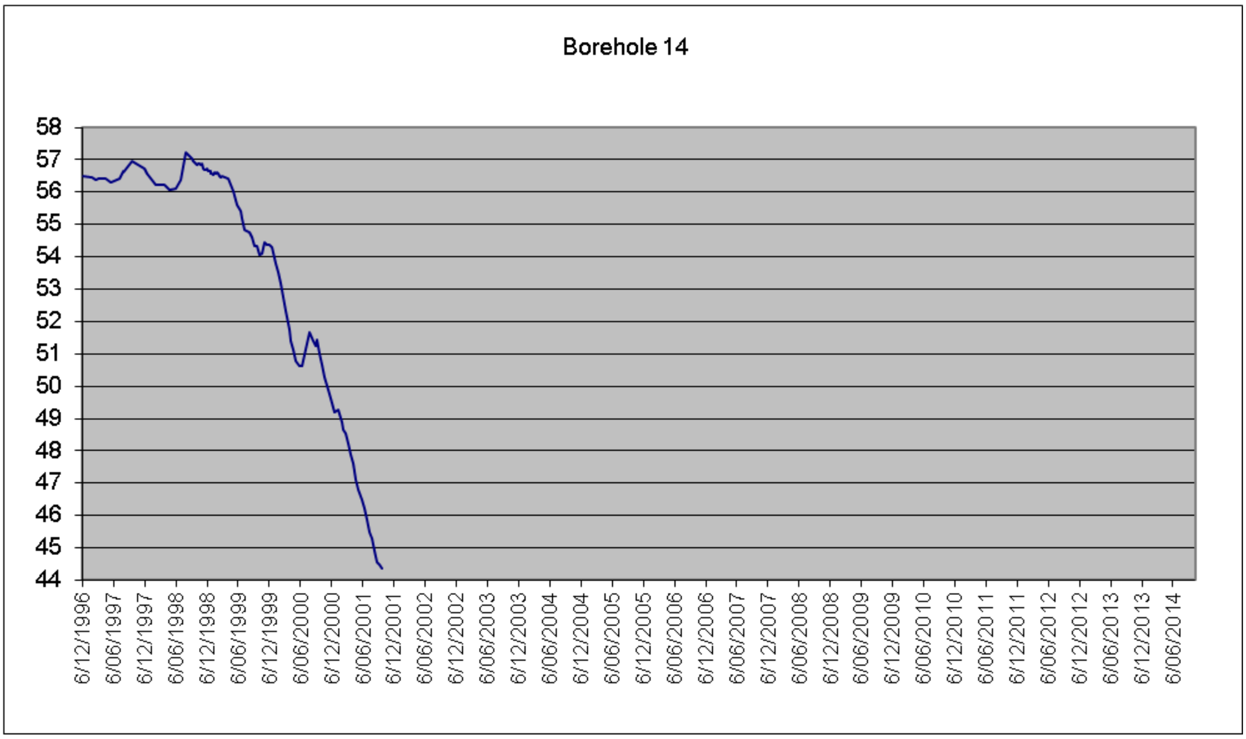
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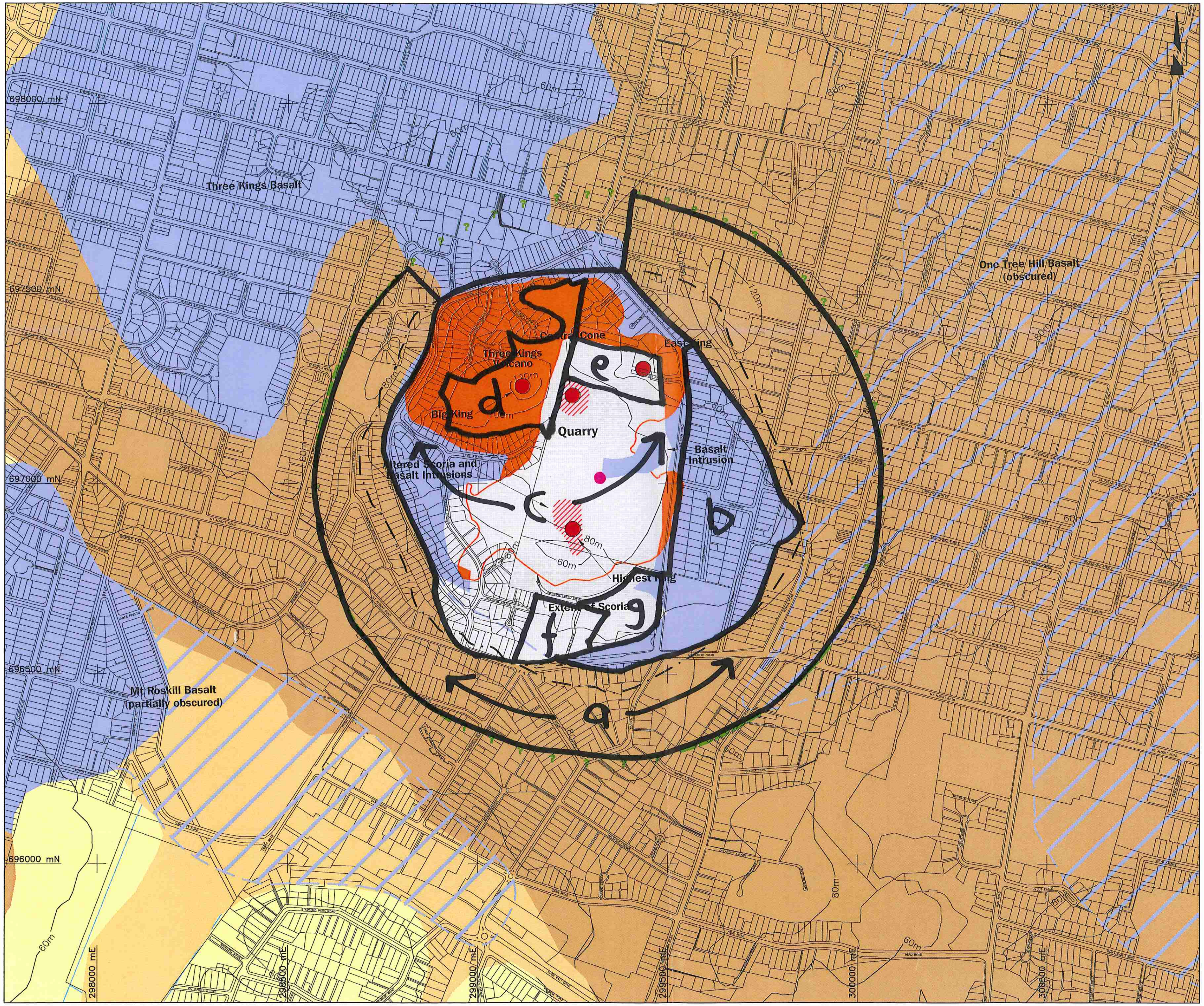
Appendix A.4

Infiltration Zones for 100 Year Storm Event



KEY:

- Centre of Crater
- Estimated extent of High Permeability Zone (Waitematas)
- Modified Areas
- Recent Deposits
- Basalt
- Obscured Basalt
- Scoria
- Tuff Deposits
- ECBF Group
- Inferred Extent of Obscured Basalt
- Three Kings Crater

Note: Geology based partly on IGNS Geological Map, Sheet R11. Base map supplied by Grant Fisher Industrial Geology, dated Dec 01, and subsequently amended by PDP Ltd (Jan 08) to clarify areas of obscured basalt.

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